Visibility Trends

http://www.epa.gov/oar/aqtrnd99/chapter6.pdf

Worth Noting:

The 10 eastern U.S. Class I area trend sites as an aggregate show a 15-percent improvement in aerosol light extinction for the haziest 20 percent of days over the 1992–1999 timeframe, with aerosol light extinction due to sulfates reaching its lowest level of the 1990s. However, visibility on the haziest 20 percent of the days remains significantly impaired with a mean visual range of 23 km for 1999 as compared to 84 km for the clearest days in 1999.

The 26 western U.S. Class I area trend sites as an aggregate show improvement in aerosol light extinction for the clearest 20 percent and middle 20 percent of days over the 1990–1999 timeframe, with a 25-percent and 14-percent improvement, respectively. The conditions for the haziest 20 percent of days degraded between 1997 and 1999 by 17 percent. However, visibility on the haziest 20 percent of the days remains relatively unchanged over the 1990s with the mean visual range for 1999 (80 km) nearly the same as the 1990 level (86 km).

Introduction

The Clean Air Act (CAA) authorizes the United States Environmental Protection Agency (EPA) to protect visibility, or visual air quality, through a number of programs. These programs include the National Visibility Program under sections 169a and 169b of the Act, the Prevention of Significant Deterioration Program for the review of potential impacts from new and modified sources, the secondary National Ambient Air Quality Standards (NAAQS) for PM_{10} and $PM_{2.5}$, and the Acid Rain Program under section 401. Since 1980, EPA issued two sets of regulations to prevent future and remedy existing visibility impairment. In 1980, EPA issued visibility regulations to address adverse impacts from a single source or small group of sources. In 1999, EPA issued regulations to address regional haze, visibility impairment caused by numerous sources located across large geographic areas.

The National Visibility Program requires the protection of visibility in 156 mandatory federal Class I areas across the country (primarily national parks and wilderness areas). The CAA established as a national visibility goal “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory federal Class I areas in which impairment results from manmade air pollution.” The Act also calls for state programs to make “reasonable progress” toward the national goal.

In 1987, the Interagency Monitoring of Protected Visual Environments (IMPROVE) visibility network was established as a cooperative effort between EPA, the National Oceanic and Atmospheric Administration, the National Park Service, the U.S. Forest Service, the Bureau of Land Management, the U.S. Fish & Wildlife Service, and state governments. The objectives of the network are to establish current conditions, to track progress toward the national visibility goal by documenting long-term trends, and to provide information for determining the types of pollutants and sources primarily responsible for visibility impairment. Chemical analysis of aerosol measurements provides ambient concentrations and associated light extinction for PM_{10}, $PM_{2.5}$, sulfates, nitrates, organic and elemental carbon, crustal material, and a number of other elements. The IMPROVE program has established protocols for aerosol, optical, and photographic monitoring methods. The IMPROVE network has been expanded from 30 to 110 sites to represent all mandatory federal Class I areas. Together with additional sites which also used the IMPROVE monitoring protocol, the total number of visibility sites now exceeds 130 nationwide. The analyses presented in this chapter are based on data from the IMPROVE network, which can be found on the Internet at: **http://vista.cira.colostate.edu/improve/Data/IMPROVE/improve_data.htm**.

This chapter presents aerosol and light extinction data collected between 1990 and 1999 at 36 Class I areas in the IMPROVE network. Because the CAA calls for the tracking of “reasonable progress” in preventing future impairment and remedying existing impairment, this analysis looks at trends in visibility impairment across the entire range of the visual air quality distribution. States are required to establish goals to improve visibility for the 20 percent worst days and to allow no degradation of the 20 percent best days as discussed later in this chapter. To facilitate this approach, visibility data have been sorted into quintiles, or 20 percent segments, of the overall distribution and average values have been calculated for each quintile. Trends are presented in terms of the haziest ("worst") 20 percent, typical ("middle") 20 percent, and clearest ("best") 20 percent of the annual distribution of data. Figure 6-1 is a map of the 36 Class I areas with seven or more years of IMPROVE monitoring data included in this analysis.

Figure 6-1. IMPROVE sites meeting data completeness requirements for sites operating in 1999.*

*Data does not include IMPROVE sites established in 2000 and 2001.

Nature and Sources of the Problem

Visibility impairment occurs as a result of the scattering and absorption of light by particles and gases in the atmosphere. It is most simply described as the haze that obscures the clarity, color, texture, and form of what we see. The same particles linked to serious health and environmental effects (sulfates, nitrates, organic carbon, elemental carbon (commonly called soot), and crustal material) also can significantly affect our ability to see.

Both primary emissions and secondary formation of particles contribute to visibility impairment. Primary particles, such as elemental carbon from diesel and wood combustion, or dust from certain industrial activities or natural sources, are emitted directly into the atmosphere. Secondary particles that are formed in the atmosphere from primary gaseous emissions include sulfate from sulfur dioxide (SO_2) emissions, nitrates from nitrogen oxide (NO_x) emissions, and organic carbon particles formed from condensed hydrocarbon emissions. In the eastern United States, reduced visibility is mainly attributable to secondarily formed particles, particularly those less than a few micrometers in diameter. While secondarily formed particles still account for a significant amount in the West, primary emissions from sources such as woodsmoke generally contribute a larger percentage of the total particulate load than in the East. The only primary gaseous pollutant that directly reduces visibility is nitrogen dioxide (NO_2), which can sometimes be seen in a visible plume from an industrial facility, or in some urban areas with high levels of motor vehicle emissions.

Visibility conditions in Class I and other rural areas vary regionally across the United States. Rural areas in the East generally have higher levels of impairment than most remote sites in the West. Higher eastern levels are generally due to higher regional concentrations of sulfur dioxide and other anthropogenic emissions, higher estimated regional background levels of fine particles, and higher average relative humidity levels. Humidity can significantly increase the effect of pollution on visibility. Some particles, such as sulfates, accumulate water and grow in size becoming more efficient at scattering light. Annual average relative humidity levels are 70–80 percent in the East as compared to 50–60 percent in many parts of the

Figure 6-2. Comparison of the three visibility metrics (extinction, deciview and visual image).

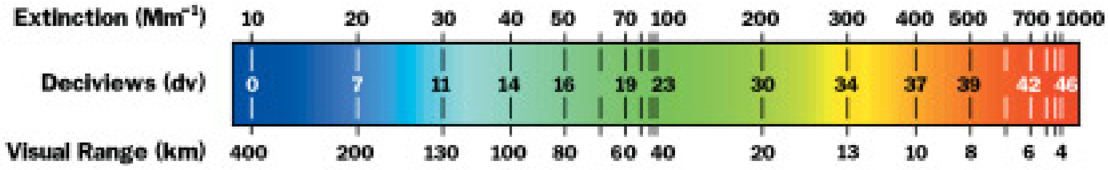
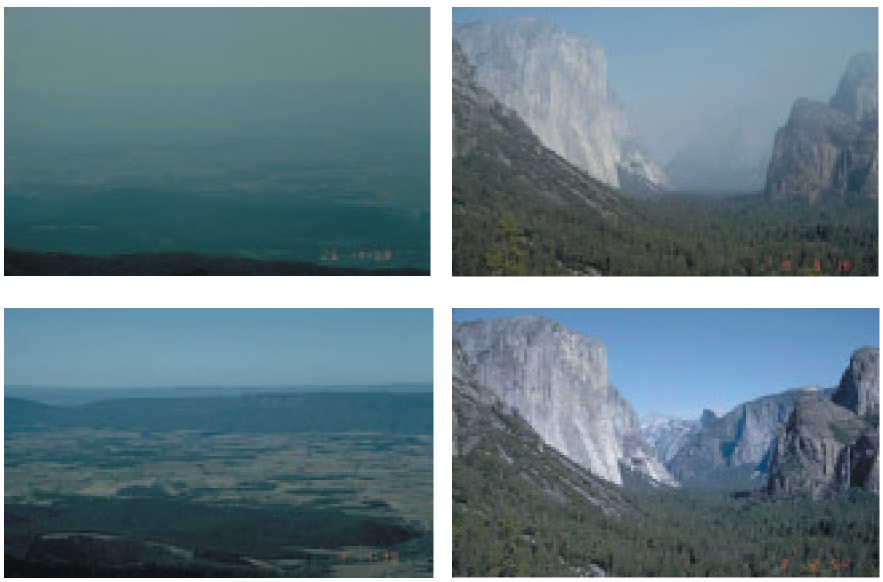


Figure 6-2a. Images of Shenandoah National Park and Yosemite National Park.



Condition: Bad
Visual Range: 25 km
Deciviews: 28

Condition: Bad
Visual Range: 16 km
Deciviews: 32

Condition: Good
Visual Range: 180 km
Deciviews: 8

Condition: Good
Visual Range: 200 km
Deciviews: 6.5

Shenandoah National Park **Yosemite National Park**

West. Poor summer visibility in the eastern United States is primarily the result of high sulfate particle concentrations combined with high humidity levels.

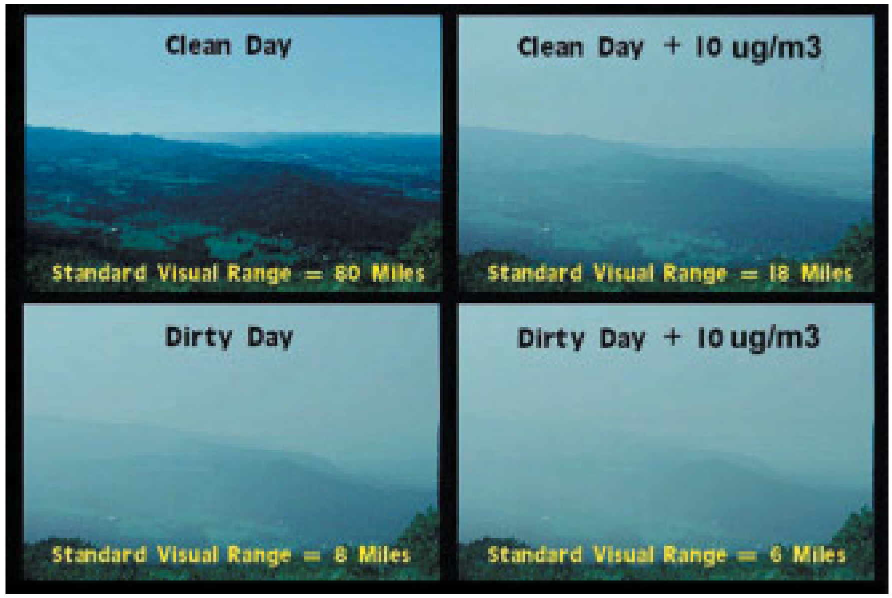
Visibility conditions are commonly expressed in terms of three mathematically related metrics: visual range, light extinction, and deciviews. Figure 6-2 shows the relationship between these three metrics of visibility. Figure 6-2a provides a photographic illustration of very clear and very hazy conditions at Shenandoah National Park in Virginia and Yosemite National Park in California. Visual range is the metric best known by the general public. It is the maximum distance at which one can identify a black object against the horizon, and is typically described in miles or kilometers.

Light extinction, inversely related to visual range, is the sum of light scattering and light absorption by particles and gases in the atmosphere. It is typically expressed in terms of inverse megameters (Mm^{-1}), with larger values representing poorer visibility. Unlike visual range, the light extinction coefficient allows one to express the relative contribution of one particulate matter (PM) constituent versus another to overall visibility impairment. Using speciated mass measurements collected from the IMPROVE samplers, “reconstructed light extinction” can be calculated by multiplying the aerosol mass for each constituent by its appropriate “dry extinction coefficient,” and then summing these values for each constituent. Because sulfates and nitrates become more efficient at scattering light with increasing humidity, these values are also multiplied by a relative humidity adjustment factor.[2] Annual and seasonal light extinction values developed by this approach correlate well with optical measurements of light extinction (by transmissometer) and light scattering (by nephelometer).

The deciview metric was developed because changes in visual range and light extinction are not proportional to human perception of visibility impairment. For example, a 5-mile (8-km) change in visual range can be either very apparent or not perceptible, depending on the base line level of ambient pollution. The deciview metric provides a linear scale for perceived visual changes over the entire range of conditions, from clear to hazy, analogous to the decibel scale for sound. Under many scenic conditions, a change of one deciview is considered to be perceptible by the average person. A deciview of zero represents pristine conditions.

It is important to understand that the same amount of pollution can have dramatically different effects on visibility depending on existing conditions. Most importantly, visibility in cleaner environments is more sensitive to increases in $PM_{2.5}$ particle concentrations than visibility in more polluted areas. This principle is illustrated in Figure 6-3, which characterizes visibility at Shenandoah National Park under a range of conditions.[3] A clear day at Shenandoah can be represented by a visual range of 80 miles (133 km), with conditions approximating naturally-occurring visibility (i.e., without pollution created by human activities). An average day at Shenandoah is represented by a visual range of 18 miles (30 km), and is the result of an additional 10 µg/m³ of fine particles in the atmosphere. The two bottom scenes, with

Figure 6-3. Shenandoah National Park on clear and hazy days and the effect of adding 10 µg/m³ of fine particles to each.



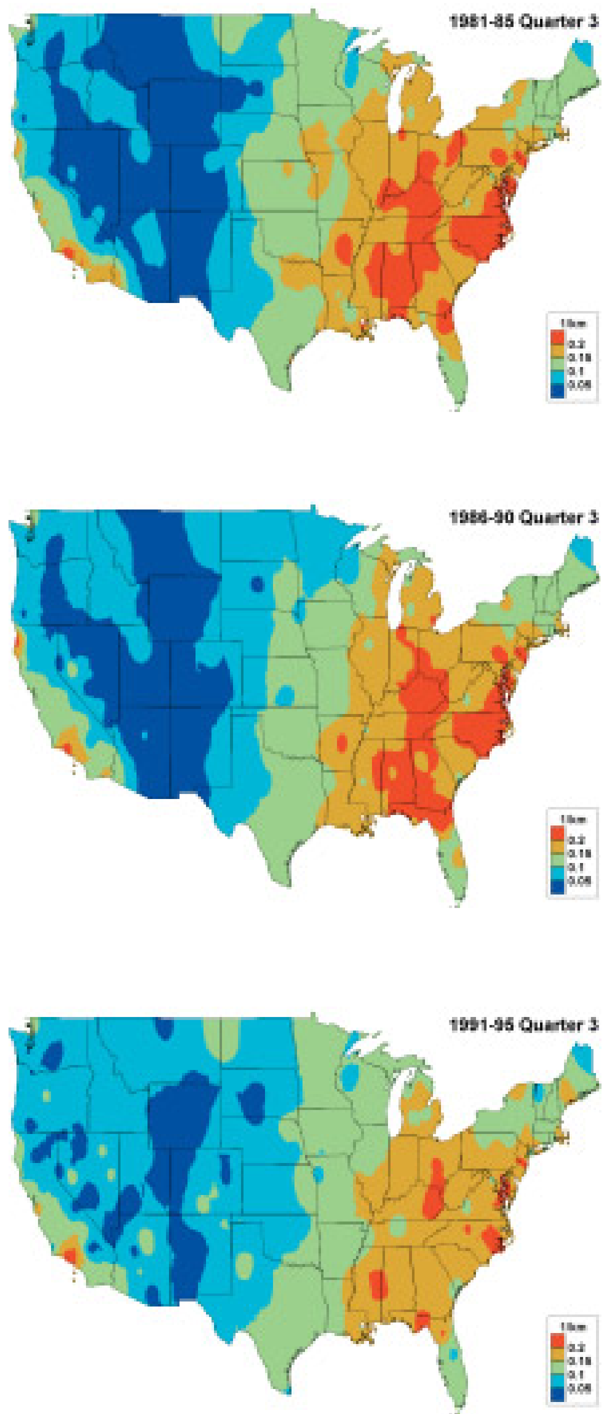
visual ranges of eight and six miles respectively, illustrate that the perceived change in visibility due to an additional 10 µg/m³ of fine particles to an already degraded atmosphere is much less perceptible than adding this amount to a clean atmosphere. Thus, to achieve a given level of perceived visibility improvement, a large reduction in fine particle concentrations is needed in more polluted areas. Conversely, a small amount of pollution in a clean area can dramatically decrease visibility.

Long-Term Trends (1981–1995)

Visibility impairment is presented here using visual range data collected since 1960 by human observers at 298 monitoring stations located at primarily urban and suburban airports across the country. Trends in visibility impairment can be inferred from these long-term records of visual range. Figure 6-4 describes long-term U.S. visibility impairment trends derived from such data.[4] The maps show the amount of haze during the summer months with each map covering five-year periods, centered at 1983, 1988, and 1993. The dark blue color represents the best visibility, and red represents the worst visibility. Overall, these maps show that summer visibility in the eastern United States improved slightly between 1980 and 1990, and continued to improve between 1991 and 1995. These trends follow overall trends in emissions of sulfur oxides during these periods.

In the early 1990s to the mid 1990s, the National Weather Service gradually switched the method used to collect visibility data presented in Figure 6-4 from human observations to automated sensors. This method change resulted in an incompatibility between the human observation and the automated sensor data. Because

Figure 6-4. Long-term trends for 75th percentile light extinction coefficient from airport visual data (July–September).



of this method change the trends presented using the human observation data in Figure 6-4 end at 1995.

Recent Trends (1990–1999) from IMPROVE Data

Visibility and aerosol light extinction data are presented for 36 sites with at least seven years of fine particle data from 1990–1999 for western sites and from 1992–1999 for eastern sites: 10 are located in the East, and 26 are located in the West, as shown in Figure 6-2. Eastern trends start in 1992 because seven sites were added to the existing three eastern sites in the IMPROVE network, bringing the total number of eastern sites to 10. This is reflected in the eastern Class I area plots, Figure 6-5a and Figure 6-6a to 6-6c, where the trend is based on eight years of data, versus 10 years of data in the western Class I area plots. Because of the significant regional variations in visibility conditions, this chapter does not present aggregate national trends, but instead groups the data into eastern and western regions. As noted earlier, trends in this chapter are presented in terms of the annual average values for the clearest ("best") 20 percent, middle ("typical") 20 percent, and haziest ("worst") 20 percent of the days monitored each year. The goals of the regional haze program are to improve visibility on the haziest days and prevent degradation of visibility on the clearest days. To date, two 24-hour aerosol samples have been taken each week from IMPROVE sites, resulting in a potential for 104 sampling days per year. In 2000, the aerosol sampling schedule was changed to one sample every three days, consistent with the approach used for national $PM_{2.5}$ aerosol monitoring.

In May of 2001, the National Park Service and other participants of the IMPROVE program identified technical concerns about measured nitrate concentrations at all IMPROVE sites prior to June 1996, and about estimates of sulfates, primarily at eastern IMPROVE sites prior to 1995. As a result, the IMPROVE monitoring data used in this year's *National Air Quality and Emissions Trends Report* is interpreted differently to correct the technical concerns. At some affected IMPROVE sites, the adjustments result in a change in the direction or significance of the reported visibility trend. Because of the new usage of the IMPROVE monitoring data, the results presented here are not directly comparable with results presented in previous *Trends* reports. A discussion of the technical concerns, the data usage, and the effect on the nitrate and sulfate data is presented on the IMPROVE website, **http://vista.cira.colostate.edu/IMPROVE/Data/QA_QC/issues.htm**.

Regional Visibility Trends for the Eastern and Western United States

Figures 6-5a and 6-5b illustrate eastern and western trends for visibility impairment in deciviews. The deciview metric used in Figures 6-5a and 6-5b best characterizes perceived changes in visibility impairment. Under many scenic conditions a change in one deciview is considered to be perceptible by the average person. These figures, presented with equivalent scales, demonstrate the regional difference in overall levels of rural visibility impairment. One can see that visibility impairment for the haziest visibility days in the West is close to the same level of impairment as seen for the best days in the East. Figure 6-5a shows that in the East, the haziest visibility days improved by

Figure 6-5a. Visibility* trends for 10 eastern U.S. Class I areas for clearest, middle, and haziest 20 percent days in the distribution, 1992–1999.

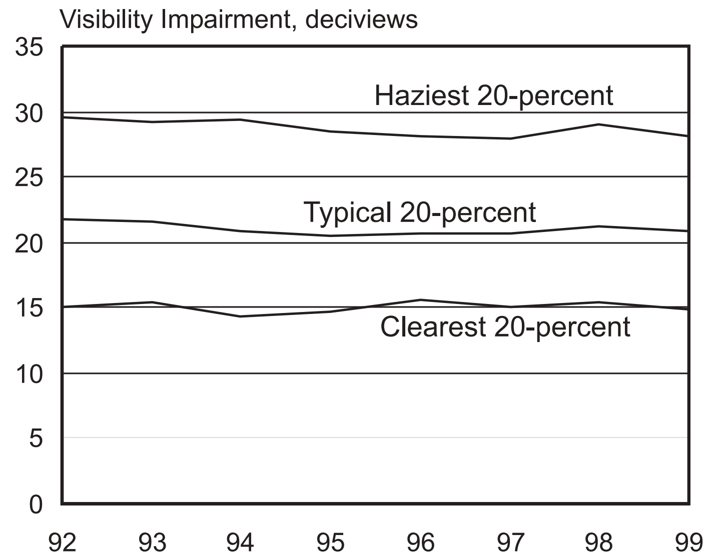
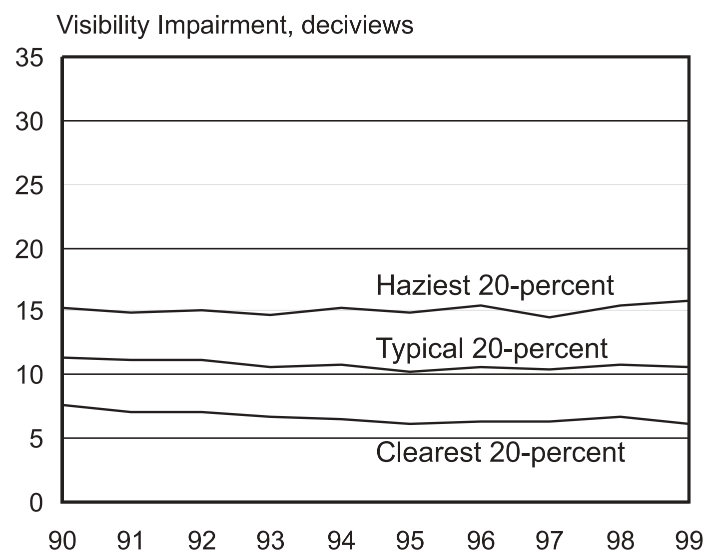


Figure 6-5b. Visibility* trends for 26 western U.S. Class I areas for clearest, middle, and haziest 20 percent days in the distribution, 1992–1999.



* For Figures 6-5a and 6-5b changes in nitrate concentrations were not considered in calculation of deciviews. A constant value based on mean 1997–1999 extinction associated with nitrates was substituted for all years.

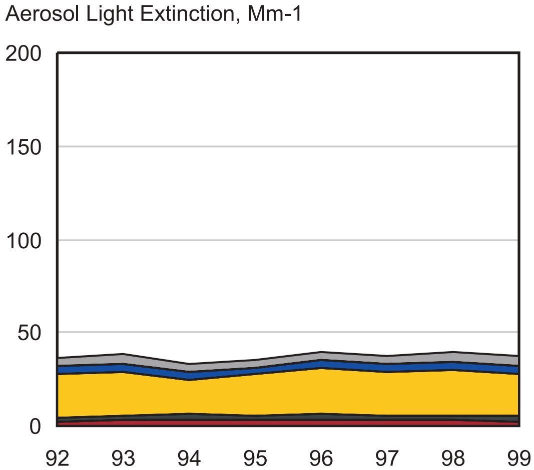
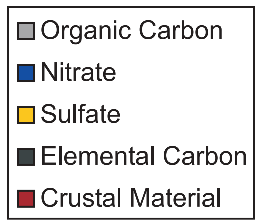


Figure 6-6a. Aerosol light* extinction in 10 eastern Class I areas for the clearest 20 percent of the days in the distribution, 1992–1999.



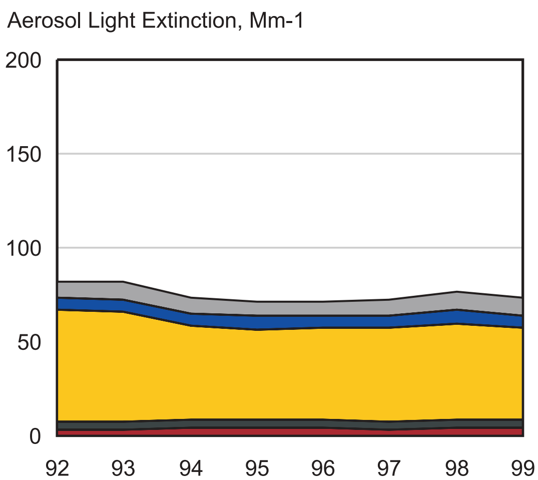


Figure 6-6b. Aerosol light* extinction in 10 eastern Class I areas for the middle 20 percent of the days in the distribution, 1992–1999.

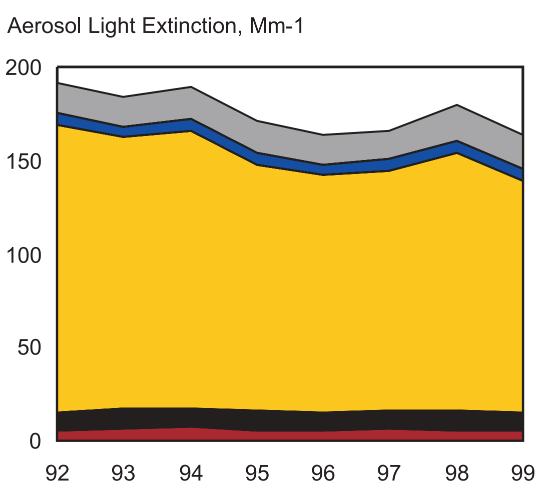


Figure 6-6c. Aerosol light* extinction in 10 eastern Class I areas for the haziest 20 percent of the days in the distribution, 1992–1999.

* For Figures 6-6a to 6-6c changes in nitrate concentrations were not considered in calculation of aerosol light extinction. A constant value based on mean 1997–1999 extinction associated with nitrates was substituted for all years.

1.5 deciviews, or 15 percent in aerosol light extinction, since 1992 based on 10 locations. Over the past two years (1998–1999) impairment on the haziest days in the East show improvement of close to 1 deciview, or 10-percent in aerosol light extinction. However, visibility for the haziest days still remains significantly impaired with a mean visual range of 23 km compared to 84 km for the clearest days in 1999. Visibility impairment in 1999 for the clearest 20 percent of days is approximately equal to 1992 levels of 15 deciviews. The typical days (or middle 20 percent of the distribution) show a 1 deciview improvement, 10 percent in aerosol light extinction, since 1992 for the 10 sites.

In the West, there appears to be visibility improvement for the clearest, and the typical, days as presented in Figure 6-5b for the period 1990–1999. Visibility impairment for the aggregate 26 western sites improved by 1.5 deciviews for the clearest days and 1 deciview for the typical days, or 25 percent and 14 percent in aerosol light extinction, respectively. Visibility impairment for the haziest days in the West degraded between 1997–1999 close to 1.5 deciviews or 17 percent in aerosol light extinction. However, visibility on the haziest 20 percent of days remains relatively unchanged over the 1990s, with the mean visual range for 1999 (80 km) nearly the same as the 1990 level (86 km).

The Components of PM Contributing to Trends in Visibility Impairment

The area plots in Figures 6-6a to 6-6f show the relative contribution to aerosol light extinction by the five principal particulate matter constituents measured by IMPROVE at eastern and western sites for the best, middle, and worst 20 percent days. Note that the scale differs for the eastern and western figures in order to more clearly present the relative contribution of the five components. By understanding the total magnitude of each $PM_{2.5}$ component, the change in aerosol composition over time, and the effect of these components on changing visibility, policymakers can design strategies to address both health and environmental concerns.

In the East, (Figures 6-6a to 6-6c), sulfate is clearly the largest contributor to visibility impairment, ranging from an average of 78–82 percent of each year's annual aerosol extinction during the haziest days to 56–63 percent on the clearest days. In 1999, eastern aerosol light extinction due to sulfates on the haziest days reached its lowest level of the 1990s with a 19-percent decline over 1992–1999. This decline in sulfates in the eastern United States and the low 1999 level corresponds to the reported regional SO_2 emissions trends and lower average sulfate aerosol concentrations discussed in Chapter 7 (Atmospheric Deposition of Sulfur and Nitrogen Compounds). Organic carbon is the next largest contributor to visibility impairment in the East, accounting for 10–14 percent of annual aerosol extinction on the best days and 8–11 percent on the most impaired days. The third largest contributor in the East is nitrate, which also accounts for about 11–13 percent of annual aerosol light extinction on the best days and about 3–4 percent on the haziest days.

In the West, sulfate is also the most significant single contributor to aerosol light extinction on the clearest, typical, and haziest days. Sulfate accounts for 33–41 percent of annual

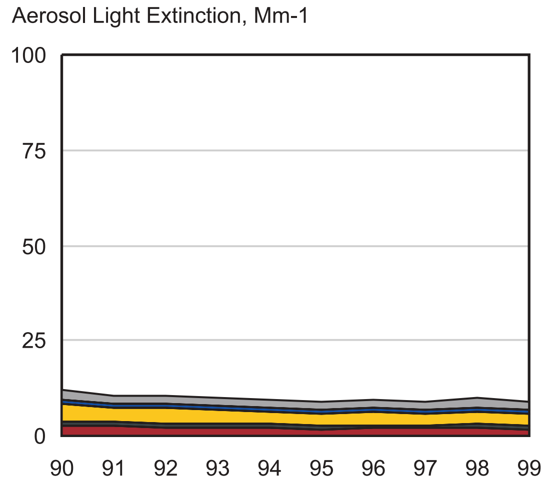
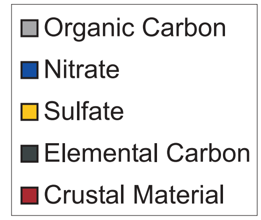


Figure 6-6d. Aerosol light* extinction in 26 western Class I areas for the clearest 20 percent of the days in the distribution, 1990–1999.



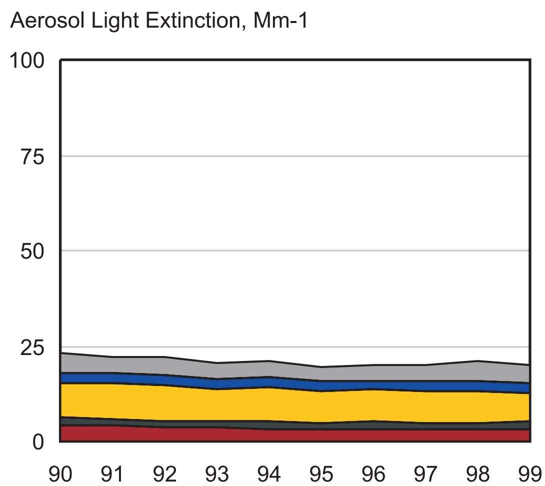


Figure 6-6e. Aerosol light* extinction in 26 western Class I areas for the middle 20 percent of the days in the distribution, 1990–1999.

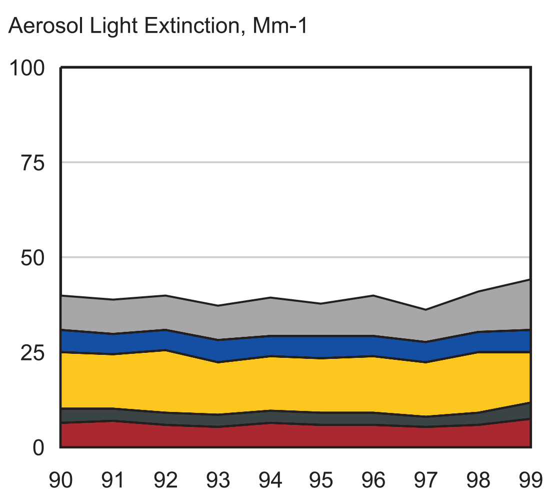
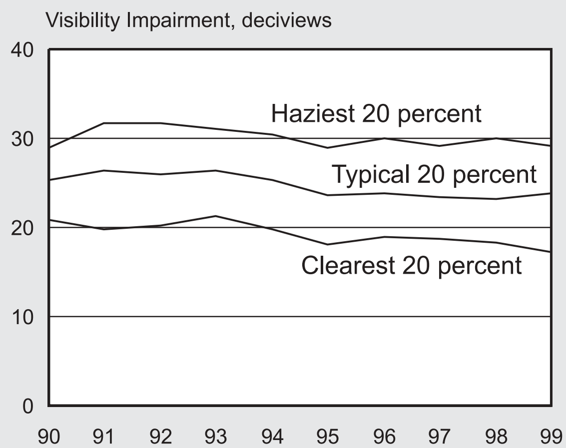


Figure 6-6f. Aerosol light* extinction in 26 western Class I areas for the haziest 20 percent of the days in the distribution, 1990–1999.

* For Figures 6-6d to 6-6f changes in nitrate concentrations were not considered in calculation of aerosol light extinction. A constant value based on mean 1997–1999 extinction associated with nitrates was substituted for all years.

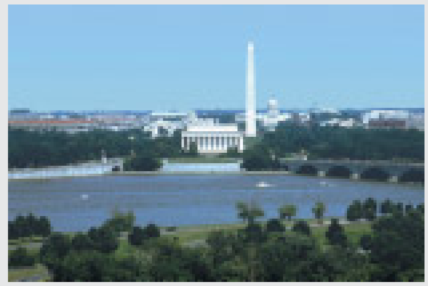
An Urban Perspective – the Washington, D.C. IMPROVE site

The only urban monitoring site with a long-term data record using the IMPROVE monitoring protocol is located in Washington, D.C. This monitor was one of the first to be deployed in 1988. The figure below illustrates the trend at the Washington, D.C. site for visibility impairment in deciviews from 1990–1999. The decrease of visibility impairment in deciviews seen from 1993–1995 for the clearest, typical, and haziest days is attributable primarily to decreases in sulfate concentrations, although nitrates and organic carbon both had large decreases during the same time period. Nevertheless, conditions of the haziest days are still significantly impaired with an average visual range of only 21 km.

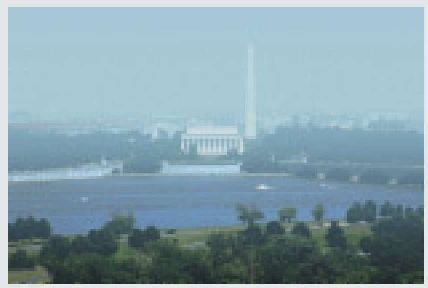


* Changes in nitrate concentrations were not considered in calculation of total light extinction. A constant value based on mean 1997–1999 extinction associated with nitrates was substituted for all years.

The photos below depict a very clear day along with a very hazy day looking across the Potomac River at the Lincoln Memorial and the Washington Monument.



Visual range > 150 km / 9.6 deciviews



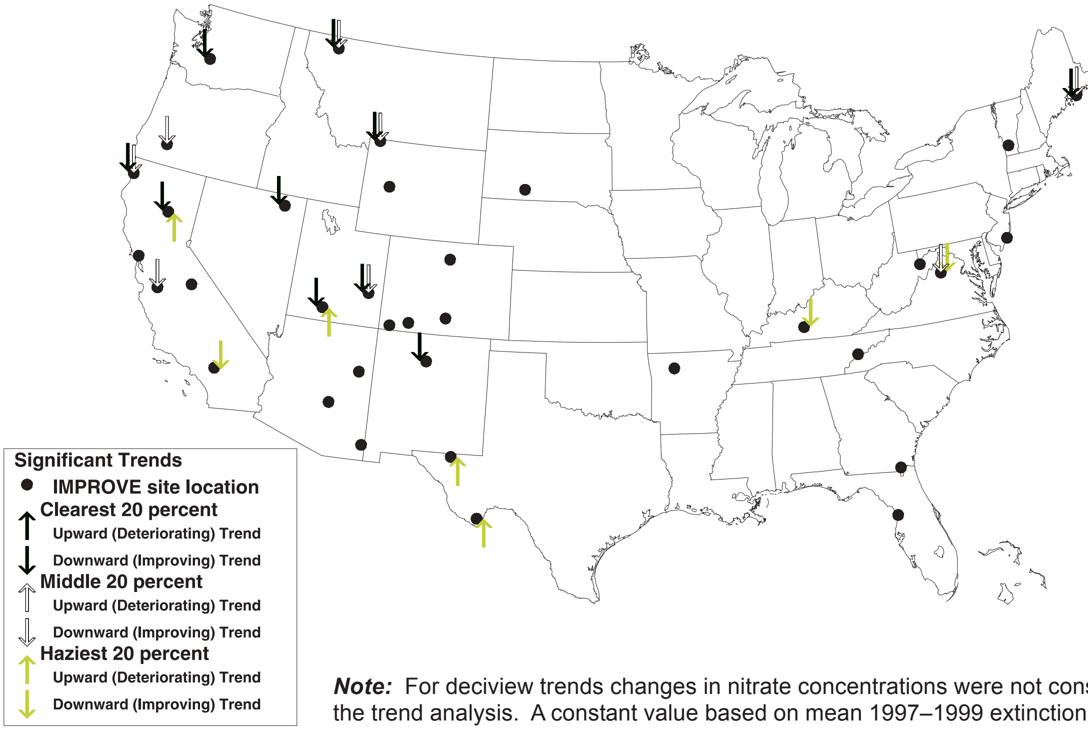
Visual range = 8.4 km / 38.4 deciviews

Table 6-1. Summary of Class I Area Trend[1] Analysis

Parameter	Number of Sites With Significant[2] Upward (*Deteriorating*) Trends West	East	Number of Sites With Significant[2] Downward (*Improving*) Trends West	East
[3]Deciviews, worst 20%	4	0	1	2
[3]Deciviews, middle 20%	0	0	6	2
[3]Deciviews, best 20%	0	0	9	1
Light extinction due to sulfate, worst 20%	4	0	4	2
Light extinction due to sulfate, middle 20%	1	1	6	4
Light extinction due to sulfate, best 20%	0	1	14	0
Light extinction due to organic carbon, worst 20%	2	0	1	0
Light extinction due to organic carbon, middle 20%	0	0	3	0
Light extinction due to organic carbon, best 20%	2	0	5	0

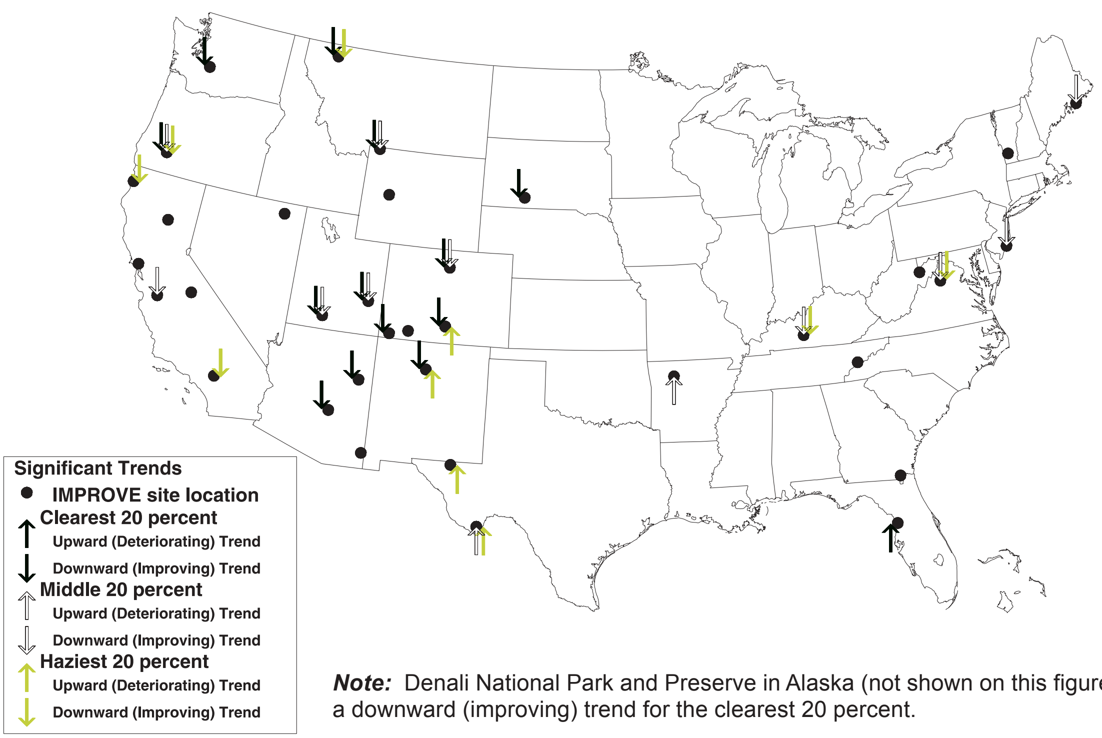
[1]Based on a total of 36 monitored sites with at least 10 years of data in the West and eight years of data in the East: 26 sites in the West, 10 sites in the East.
[2]Statistically significant at the 5-percent level.
[3]For deciview trends changes in nitrate concentrations were not considered in the trend analysis. A constant value based on mean 1997–1999 extinction associated with nitrates was substituted for all years.

Figure 6-7a. Class I area significant trends in deciviews for the clearest 20 percent, middle 20 percent, and haziest 20 percent days as summarized in Table 6-1.



Note: For deciview trends changes in nitrate concentrations were not considered in the trend analysis. A constant value based on mean 1997–1999 extinction associated with nitrates was substituted for all years.

Figure 6-7b. Class I area significant trends light extinction due to sulfate for the clearest 20 percent, middle 20 percent, and haziest 20 percent days as summarized in Table 6-1.



Note: Denali National Park and Preserve in Alaska (not shown on this figure) showed a downward (improving) trend for the clearest 20 percent.

Figure 6-7c. Class I area significant trends for light extinction due to organic carbon for the clearest 20 percent, middle 20 percent, and haziest 20 percent days as summarized in Table 6-1.

aerosol light extinction on the best days, 39–43 on the typical days, and 31–42 on the haziest days. However, organic carbon (19–30 percent), crustal material (14–26 percent), and nitrates (9–15 percent) play a more significant role (as a percentage of aerosol extinction) in western sites as compared to eastern ones. Since 1990, western visibility (as aggregated across 26 areas) has improved slightly on the best days and typical days. On the haziest days, light extinction generally decreased through 1997, but it increased by 22 percent between 1997–1999. It appears that this increase in light extinction was primarily due to increases in organic carbon and crustal material.

Trends in Specific Class I Areas

IMPROVE data from 36 Class I area monitoring sites[1] were analyzed for upward or downward trends using a nonparametric regression methodology described in Appendix B: Methodology.

Table 6-1 summarizes the trends analysis performed on these 36 sites for total light extinction (expressed in deciviews), light extinction due to sulfates and light extinction due to organic carbon on an area-by-area basis. Figures 6-7a–c show the significant trends for the Class I areas as summarized in Table 6-1. A solid dot indicates the IMPROVE monitoring site location. The arrow is pointing up for a deteriorating trend and down for an improving trend. The different color arrows represent the clearest 20 percent of days, typical (middle) 20 percent of days, and haziest 20 percent of days. As shown in Figure 6-7a several sites with improving trends show improvement in more than one of the three quintiles, especially in the West. Figures 6-7b and 6-7c show the trends associated with aerosol light extinction due to sulfate and organic carbon, respectively. Trends in the individual constituents, like sulfate and organic carbon, often appear earlier than trends for total aerosol light extinction.

Current Visibility Conditions

Current annual average conditions range from about 18–40 miles in the rural east and about 35–90 miles in the rural west. On an annual average basis, natural visibility conditions have been estimated at approximately 80–90 miles in the East and up to 140 miles in the West.[3] Natural visibility varies by region, primarily because of slightly higher estimated background levels of $PM_{2.5}$ in the East, and the more significant effect of relative humidity on particle concentrations in the East than in the West.

Figure 6-8a. Aerosol light extinction in (Mm^{-1}) for the clearest 20 percent days and contribution by individual particulate matter constituents, based on 1997–1999 IMPROVE data.

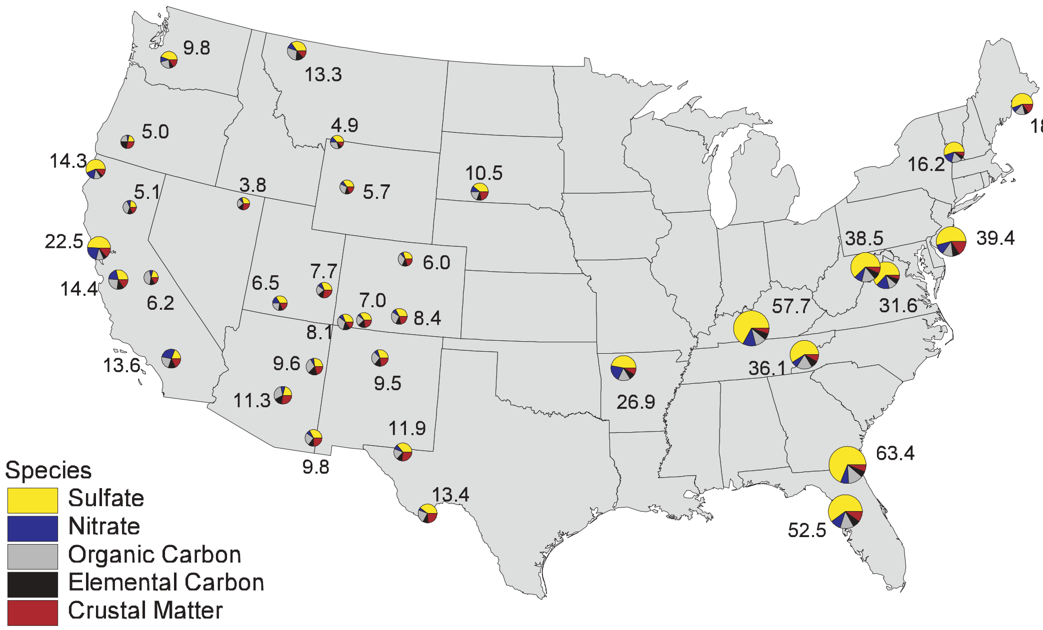


Figure 6-8b. Aerosol light extinction in (Mm^{-1}) for the middle 20 percent days and contribution by individual particulate matter constituents, based on 1997–1999 IMPROVE data.

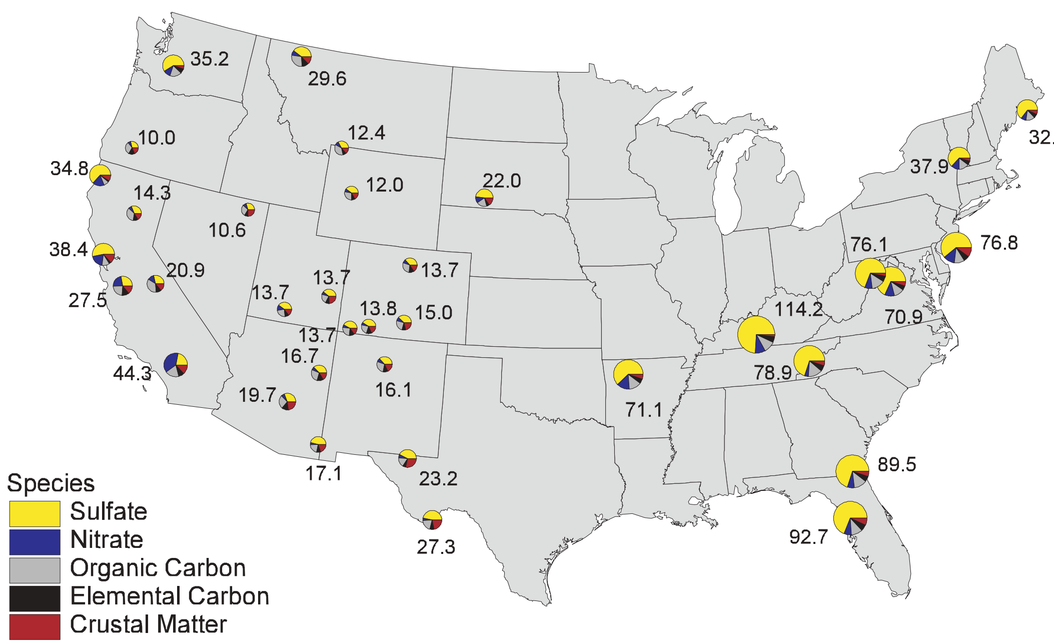
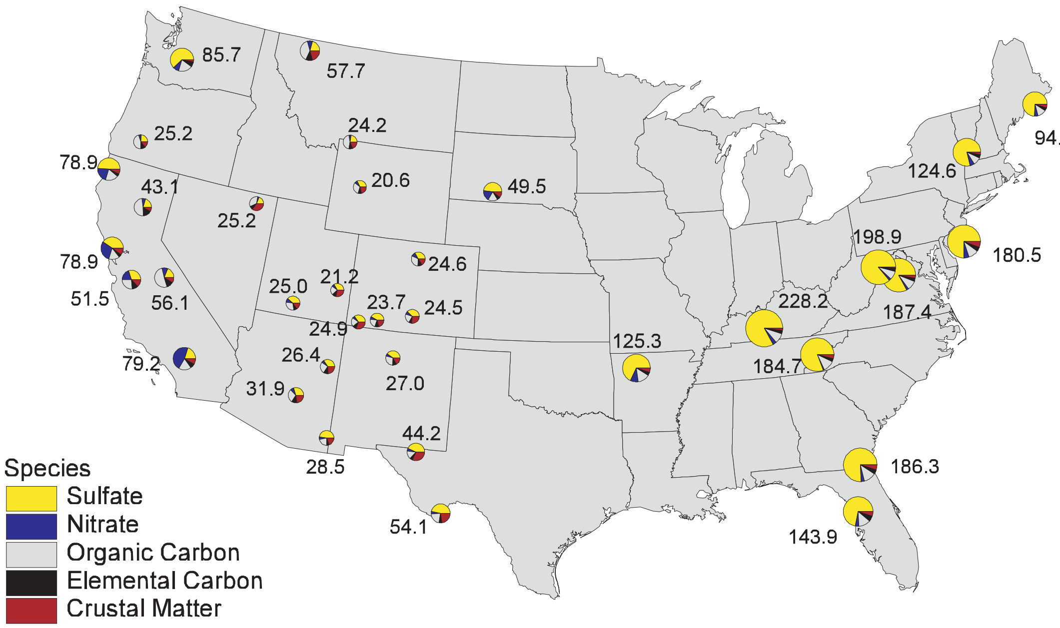


Figure 6-8c. Aerosol light extinction in (Mm^{-1}) for the haziest 20 percent days and contribution by individual particulate matter constituents, based on 1997–1999 IMPROVE data.



Note: For Figures 6-8a to 6-8c changes in nitrate concentrations were not considered in calculation of aerosol light extinction.

Figures 6-8a to 6-9c illustrate regional visibility impairment in terms of reconstructed aerosol light extinction based on measurements at IMPROVE sites between 1997 and 1999. Maps are presented for the clearest, typical, and haziest 20 percent of the distribution. The pie charts show the relative contribution of different particle constituents to visibility impairment. Annual average aerosol light extinction due to these particles is indicated by the value next to each pie and by the size of each pie.[1] Figure 6-8 also shows that visibility impairment is generally greater in the rural east compared to most of the West. As noted earlier, the pies show that, for most rural eastern sites, sulfates account for more than 60 percent of annual average light extinction on the best days and up to 86 percent of annual average light extinction on the haziest days. Sulfate particles play a particularly significant role in the humid summer months due to their ability to take on moisture and become more efficient at scattering light, most notably in the Appalachian, northeast, and mid-south regions. The figures also show that organic carbon and nitrates each account for 10–18 percent and 7–16 percent respectively of aerosol extinction on the clearest days while elemental carbon only contributes 5–8 percent. On the other hand, organic carbon contributes around 11 percent to aerosol light extinction on the haziest days while nitrates and elemental carbon each typically contribute 1–6 percent.

In the rural west, sulfates also play a significant role, typically accounting for about 30–40 percent of aerosol light extinction on the best days and 30–45 percent on the haziest days. In several areas of the West, however, sulfates account for over 50 percent of annual average aerosol extinction, including Mt. Rainier, WA, and Redwood National Park, CA. In contrast, it contributes less than 25 percent in southern California. Organic carbon typically makes up 25–40 percent of aerosol light extinction in the rural west, elemental carbon (absorption) accounts for about 10 percent, and crustal matter (including coarse PM) accounts for about 15–25 percent. Nitrates typically account for less than 10 percent of total light extinction in western locations, except in the southern California region where it accounts for 30-45 percent.

Figures 6-9a to 6-9c illustrate current levels of visibility impairment, in terms of deciviews, for the clearest, typical, and haziest 20 percent days based on IMPROVE data from 1997–1999.[1] Note that the deciview scale is more compressed than the scale for

Figure 6-9a. Current visibility impairment expressed in deciviews for the clearest 20 percent days based on 1997–1999 IMPROVE data.

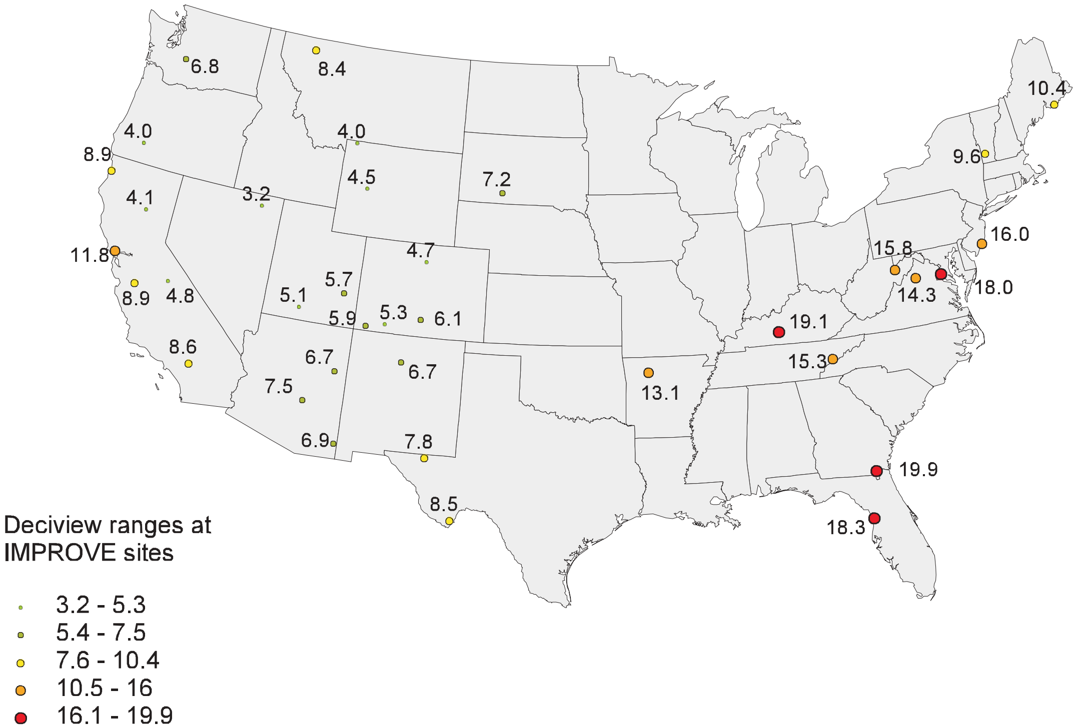


Figure 6-9b. Current visibility impairment expressed in deciviews for the middle 20 percent days based on 1997–1999 IMPROVE data.

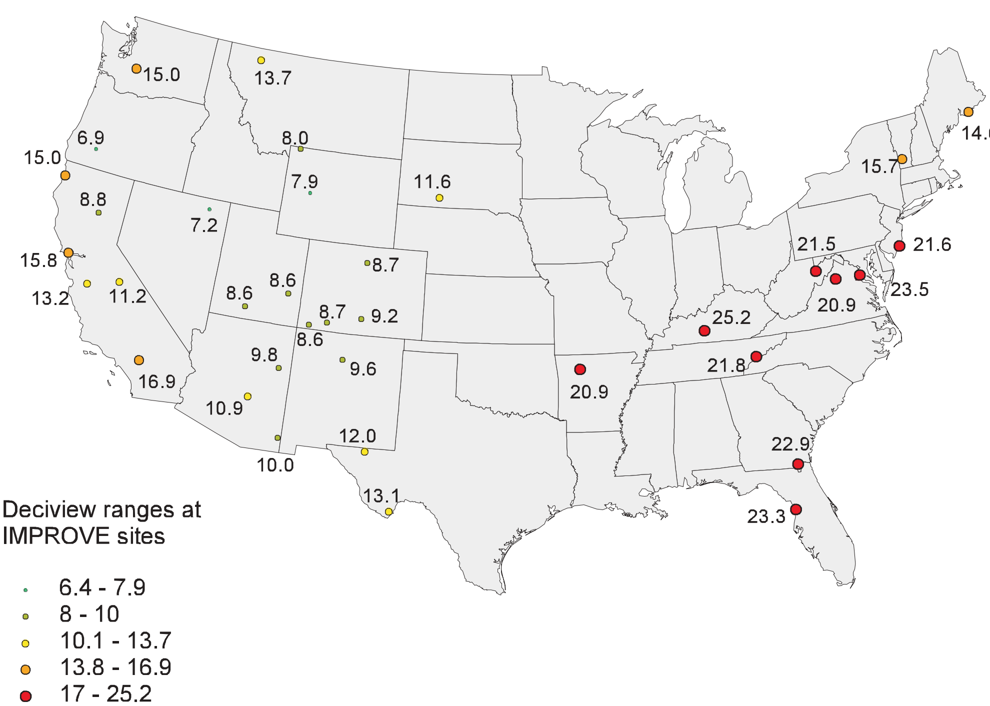
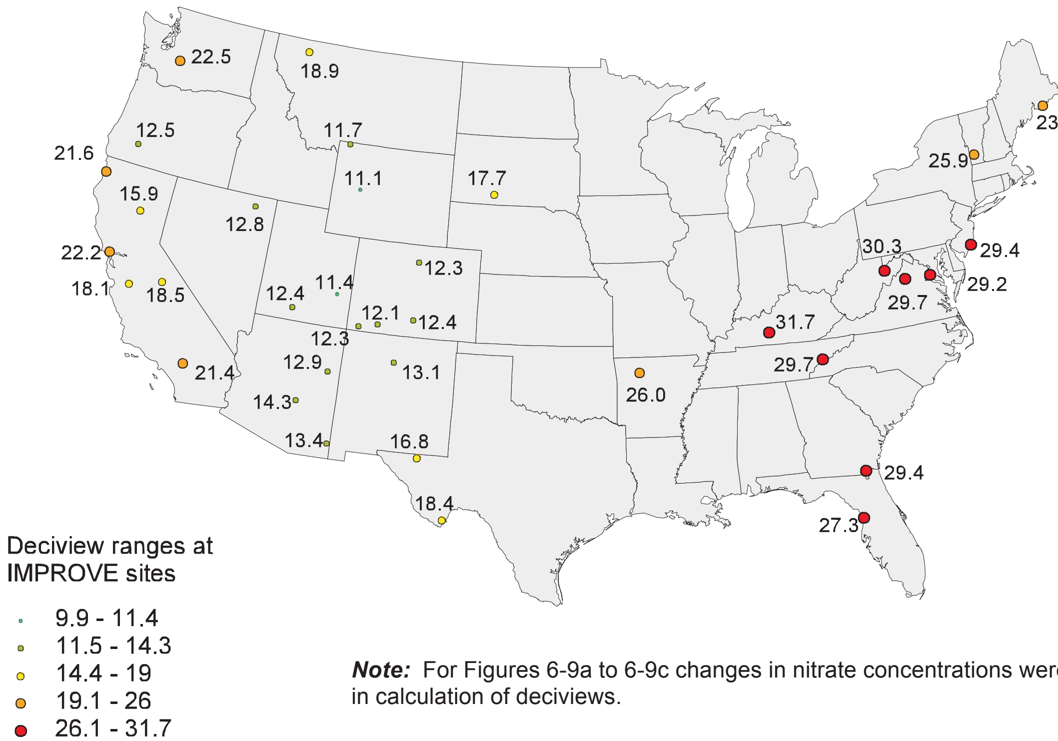


Figure 6-9c. Current visibility impairment expressed in deciviews for the haziest 20 percent days based on 1997–1999 IMPROVE data.



Note: For Figures 6-9a to 6-9c changes in nitrate concentrations were not considered in calculation of deciviews.

visual range or light extinction, with larger values representing greater visibility degradation. Most of the sites in the intermountain west and Colorado Plateau have annual average impairment of 12 deciviews or less, with the worst days ranging up to 17 deciviews. Several other western sites in the northwest and California experience levels on the order of 16–23 deciviews on the haziest 20 percent of days. Many rural locations in the East have annual average values exceeding 21 deciviews, with average visibility levels on the haziest days up to 32 deciviews.

Programs to Improve Visibility

In April of 1999, EPA issued the final regional haze regulation.[5] This regulation addresses visibility impairment in national parks and wilderness areas that is caused by numerous sources located over broad regions. The program lays out a framework within which states can work together to develop implementation plans that are designed to achieve "reasonable progress" toward the national visibility goal of no human-caused impairment in the 156 mandatory Class I federal areas across the country.

States are required to establish goals to improve visibility on the 20 percent worst days and to allow no degradation on the 20 percent best days for each Class I area in the state. In establishing any progress goal, the state must analyze the rate of progress for the next 10–15 year implementation period which, if maintained, would achieve natural visibility conditions by 2064. The state will need to show whether this rate of progress or another rate is more reasonable based on certain factors in the Clean Air Act, including costs and the remaining useful life of affected sources. Along with these goals, the state plans also must include emission reduction measures to meet these goals (in combination with other states' measures), requirements for Best Available Retrofit Technology on certain large existing sources (or an alternative emissions trading program), and visibility monitoring representative of all Class I areas.

State regional haze plans are due in the 2003–2008 timeframe. Because of the common precursors and the regional nature of the PM and regional haze problems, the haze rule includes specific provisions for states that work together in regional planning groups to assess the nature and sources of these problems and to develop coordinated, regional emission reduction strategies. One provision allows nine Grand Canyon Visibility Transport Commission States (Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, Utah, and Wyoming) to submit initial plans in 2003 to implement their past recommendations within the framework of the national regional haze program. Another provision allows certain states until 2008 to develop coordinated strategies for regional haze and PM contingent upon participation in regional planning groups. For additional information on the regional haze program, go to EPA's website: **http/www.epa.gov/air/visibility**.

Implementation of the PM and ozone NAAQS in conjunction with a future regional haze program is expected to improve visibility in urban as well as rural areas across the country. Other air quality programs are expected to bring about emissions reductions that will improve visibility in certain regions of the country. The acid rain program will achieve significant regional reductions in the emissions of SO_2, which will reduce sulfate haze particularly in the eastern United States. When implemented, the NO_x State Implementation Plan (SIP) call to reduce emissions from sources of NO_x to reduce formation of ozone should also improve regional visibility conditions to some degree. In addition, visibility impairment in Class I areas should improve as a result of a number of other programs, including mobile source emissions and fuel standards, certain air toxics standards, and implementation of smoke management and woodstove programs to reduce fuel combustion and soot emissions.

References

1. Data from IMPROVE Visibility Monitoring Network, 1999.

2. Sisler, J. *Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States: Report III*. Colorado State University, Cooperative Institute for Research in the Atmosphere. Fort Collins, CO., 2000.

Also see: Sisler, J. *Spatial and Seasonal Patterns and Long-Term Variability of the Composition of the Haze in the United States: An Analysis of Data from the IMPROVE Network*. Colorado State University, Cooperative Institute for Research in the Atmosphere. Fort Collins, CO, 1996.

Sisler, J., Huffman, D., and Latimer, D. *Spatial and Temporal Patterns and the Chemical Composition of the Haze in the United States: An Analysis of Data from the IMPROVE Network, 1988–1991*, Colorado State University, Cooperative Institute for Research in the Atmosphere. Fort Collins, CO, 1993.

Also see (Submitted for publication) Sisler, J., and Malm, W.C. "Interpretation of Trends of $PM_{2.5}$ and Reconstructed Visibility from the IMPROVE Network," Journal of the Air and Waste Management Association, 1998.

3. Irving, P.M., ed., *Acid Deposition: State of Science and Technology, Volume III, Terrestrial, Materials, Health, and Visibility Effects*, The U.S. National Acid Precipitation Assessment Program, Chapter 24, page 24–76.

4. Schichtel, B.A., J.B. Husar, S.R. Falke, and W.E. Wilson. "Haze Trends of the United States, 1980–1995," *Atmospheric Environment* in press.

5. The final regional haze rule was signed on 4/22/99 and published in the *Federal Register* on 7/1/99 (*64FR35713*).